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**OPTIMAL JOINT LIABILITY LENDING AND
WITH COSTLY PEER MONITORING**

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Optimal Joint Liability Lending and with Costly Peer Monitoring

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Abstract

This paper characterizes an optimal group loan contract with costly peer monitoring. Using a fairly standard moral hazard framework, we show that the optimal group lending contract could exhibit a joint-liability scheme. However, optimality of joint-liability requires the involvement of a group leader, who heavily takes care of the partner's repayment share in bad states and gets compensated in expected terms. This key result holds even for a group of borrowers, which exhibits homogeneous characteristics in productivity, risk aversion and monitoring costs. Our work rationalizes the widely-applied *group-leadership* concept of microfinance programmes as an outcome of an optimal contract.

Keywords: Micro-finance, Joint-liability, Group leader.

JEL Classification Numbers: G21, O12, 016.

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1 Introduction

Group loan contracts with joint-liability schemes are extensively utilized by microfinance programmes in developing countries, and especially in rural borrowing environments with weak institutions. The success of Grameen Bank and other microcredit institutions in implementing group enforcement mechanisms drew attention to understanding the efficiency of joint liability agreements. In this paper we analyze the efficiency of a group lending model where intra-group monitoring and thus joint liability agreements are costly to produce.

We develop a fairly general group lending framework where intra-group monitoring determines the benefits from private benefit actions, where the easier monitoring the higher is the quantity of loans that can be extended to the group. Since effort needs to be spent to monitor, a borrower chooses to monitor his peer only if this is in his best interest. Therefore, the bank has to consider borrowers' incentives at making them jointly liable for each other's behavior.

Under this framework, we characterize the optimal group lending contract. The optimal group contract - that induces peers to monitor each other and maximizes loan repayment - exhibits a joint liability scheme. Furthermore, we show that the optimality requires a group leader, who overpays in bad states and heavily takes care of the joint-liability scheme and gets compensated in expected terms. This key result holds even for a group of borrowers, which exhibits homogeneous characteristics in productivity, risk aversion and monitoring costs. The intuition is related to the cost minimizing incentives that a profit maximizing microfinance institution chooses to provide: The absence of a group leader generates the possibility of multiple equilibria which undermines group's commitment to repay. In this respect, our results rationalize the widely applied group leader practice of microfinance programmes as an outcome of an optimal lending contract.

Leading microfinance institutions all around the world employ group leadership practices

in order to maintain discipline, distribute information and facilitate repayments. In other words, the group leader functions as an intermediary between the group of borrowers and the bank. A number of empirical studies highlighted the role of group leaders in enhancing the performance of joint liability contracts. For instance, Paxton et al. (2000) use data of 140 group borrowers from a micro lending institution in Burkina Faso and find that the quality of the group leader in running the group transactions is positively related to the repayment performance, which may be seen as evidence for the importance of the group leader at joint-liability schemes. Hermes et al. (2005) investigate the role of the group leader in reducing moral hazard. The authors use a dataset of 102 groups from Eritrean group lending institutions. They find evidence that the monitoring effort of the group leader reduces moral hazard behaviour of group members. In a related paper the same authors also show that the role of the group leader is highly relevant for improving the repayment performance of the group (Hermes et al. (2006)).

Although microfinance lending alleviates the financing constraints on the poor, empirical evidence such as in Islam et al. (2015) show that micro-lending does not necessarily facilitate new business opportunities. In a related research, Garmaise and Natividad (2010) show that relieving information problems can significantly enhance operational efficiency of microfinance institutions. There is a theoretical literature that aims to understand the efficiency of microfinance programmes with a particular focus on understanding the functioning of joint-liability group contracts in alleviating frictions caused by informational asymmetry and enhancing productive business investment. In this respect, on the one hand, Ghatak and Guinnane (1999) and Ghatak (2000) show that joint-liability lending contracts could induce endogenous peer selection, state verification and endogenous enforcement of repayment. Therefore, these studies argue that joint liability contracts can improve welfare and repayment rates if standard screening instruments such as collateral are unavailable. On the other hand, Gangopadhyay et al. (2005) claim that the joint liability lending contracts might violate an ex post incentive-compatibility constraint which says that the amount of joint liability cannot exceed the amount of individual liability. Other concerns have been raised about the efficiency of joint liability lending contracts. Rai and Sjöström (2004)

show that it is the ability to side-contract and cross-report that is crucial for the efficiency of group loan contracts and not necessarily the joint-liability scheme itself. Our paper contributes to this debate by providing a characterization of optimal group lending contracts with costly monitoring and showing that the optimality of joint-liability requires the incentivization of a group leader.

Existing theoretical literature on joint liability lending mostly ignores the role of a group leader in fostering the performance of group lending mechanisms. The institutional lending practices mentioned above as well as the empirical evidence suggest that understanding the benefits of group leadership deserves attention. To the best of our knowledge, the two exceptions in the literature are van Eijkel et al. (2009) and Katzur and Lensink (2010). Van Eijkel et al. (2009) show that in a group lending contract the entrepreneur with the highest future profits is motivated to put the highest effort to peer monitor and would desire to become the group leader. Similarly, Katzur and Lensink (2010) find that a relatively risky borrower would have the motivation to act as a group leader and take responsibility for his peers' repayment, in return for a discount on his own loan repayment.

The key difference between our model and the two studies mentioned above is that we do not assume any ex-ante heterogeneity in exogenous characteristics within the group, such as heterogeneity in risk attitudes and profitability. Furthermore, we derive the key features of the group leader from an optimal joint liability contract. Therefore, our paper makes several key contributions to the theoretical literature on joint-liability lending. First and foremost, we characterize the properties of an optimal group lending contract, which minimizes bank's cost of lending. As highlighted by Bubna and Chowdhry (2010), financial intermediaries all around the world are seeking profitable mechanisms for participating in micro lending. Second, we derive the key characteristics of a group leader that are comparable to the group leader features observed in practice. Third, we show that optimal contracts imply the desirability of a group leader even within a group of borrowers with homogeneous characteristics. And fourth, our characterization addresses the question of why someone would be willing to become a group leader and undertake a socially desir-

able but individually costly action by showing that the group leader who takes care of the burden of joint-liability gets compensated in expected terms at an optimal joint liability contract.

There are also a number of papers that emphasize the importance of social sanctions as disciplining devices at group loan contracts. Some examples are Besley and Coate (1995), Wydick (1999), de Aghion (1999), and de Aghion and Murdoch (2000). Our paper endogenizes the provision of such social punishment devices and shows that unless group lending contracts are supported with heterogeneity in repayment rates across borrowers at different states of the nature, social sanctions are too costly to produce.

The rest of the paper is organized as follows. Section 2 presents a standard lending problem with moral hazard a la Holmstrom and Tirole (1997). In sections 3 and 4, we extend this lending problem into a group lending framework, solve the optimal lending contract and characterize the features of the group leader. Section 5 provides a discussion of our results and section 6 concludes.

2 The Lending Problem

We consider a lending problem with moral hazard a la Holmstrom and Tirole (1997). Suppose that there is a risk-neutral bank and two risk-neutral borrowers. The borrowers are indexed as 1 and 2. Borrowers need 100% external finance to run investment projects, where finance can be provided by the bank. Each borrower has access to a set of mutually exclusive projects, and in the absence of right incentives they could react opportunistically and reduce the probability of project success in order to enjoy a private benefit. Formally, each borrower can privately choose one of the three project options that we illustrate in table 1.

We assume that the probability of success of the good project is greater than the success probability of bad (private benefit) projects, $p_i > p_B$, where i indexes the borrower with

$i \in \{1, 2\}$. Private benefits are ordered as $B > b > 0$. The private benefits can be interpreted as opportunity costs from managing the project diligently. Either level of shirking produces the same probability of success. This has the convenient implication that the entrepreneur will prefer the high private benefit project (B-project) over the low private benefit project (b-project) under any un-monitored loan contract.

	Good	Bad Low Pr. Benefit	Bad High Pr. Benefit
Projects (Private Benefits)	0	b	B
Prob. of Success	p_i	p_B	p_B

Table 1: Investment Projects

Each project requires 1 unit of cash investment and generates a verifiable financial return equaling either 0 (failure) or θ (success). We assume that the opportunity cost of unit cash is 1. Furthermore, the rate of return on invested capital satisfies

$$p_i\theta > 1 > p_B\theta + B,$$

which implies that the high private benefit projects are socially undesirable. The bank can pay ψ^{bank} units of cash in order to eliminate the B-project from a borrower's feasible set of investment projects. By construction, we assume that it is too costly for the bank to rule out the action B with individual contracts because monitoring cost per unit cash invested, ψ^{bank} , is too large. Formally, we assume that

$$\psi^{bank} > p_i\theta - 1.$$

As we will illustrate in the next section, we assume that the only feasible lending option in the economy is through peer monitored joint liability contracts.

3 Group Lending with Peer Monitoring

In this section, we incorporate peer monitoring into the framework that we presented in section 2. The borrower i could pay ψ^i , which is non-verifiable by the bank, and eliminate the high private benefit action from borrower j 's feasible project set.

We assume that

$$\psi^i < \psi^{bank} \text{ for } i \in \{1, 2\}.$$

Bank will desire to mobilize the peer monitoring within the group in order to minimize incentives to take private benefit actions and maximize repayment from the group loan. The timing of actions that we consider can be represented as dynamic game consisting of two-stages:

Stage 1:

- Borrowers 1 and 2 apply for the group lending contract.
- Bank decides on whether to extend 1 unit of cash to each borrower.
- The terms of the group loan contract are decided.
- Borrowers 1 and 2 simultaneously choose the monitoring effort - formally, whether to spend ψ_i - conditional on having obtained finance.
- Borrowers' monitoring efforts are revealed to each other, but not to the bank.

Stage 2:

- Borrower 1 and 2 decide which project to take.
- Project returns are realized.
- Borrower 1 and 2 repay back to the bank, where individual specific repayment rates - as determined by the contractual terms - can be conditional on the realization of one's own project success as well as his peer's project success.
- Borrowers and bank consume.

4 Optimal Group Loan Contract

In this section we solve for the optimal group loan contract. In this respect, at first we would like to note that the only observable (and hence contractible) variables for the bank are borrower 1 and borrower 2 project realizations. Letting $s_i \in \{H, L\}$ be the realization of the borrower i 's project, we formally define an optimal group loan contract as follows.

Definition A group loan contract is a collection of repayment functions $(R_i^{s_i, s_{-i}})_{i=1,2}$. For instance, $R_1^{H,L}$ is borrower 1's repayment when his project return is in state $s_1 = H$, while borrower 2 project return is in the low state, $s_2 = L$.

Given the sequence of actions, in the first stage of the dynamic game, each borrower decides whether to monitor or not. Afterwards, in the second stage, borrowers decide on which projects to undertake. Formally, a strategy for borrower i is a pair of functions $\delta_i : \{\emptyset\} \rightarrow \{m, n\}$, and $e_i : \mathcal{H} \rightarrow \mathcal{A}_i$, where m stands for *monitoring*, n for *no monitoring*, \mathcal{H} is the collection of possible histories after the first stage game, and $\mathcal{A}_i \subset \{0, b, B\}$ is the collection of player i 's feasible project opportunities in the second-stage game - characterized as the amount of private benefits that each project can generate.

Each borrower's project choice in the second stage depends on the contractual terms $(R_i^{s_i, s_{-i}})_{i=1,2}$, and on whether he got monitored in the first stage or not and finally also on the expectations regarding the peer borrower's project choice. We restrict our attention to contracts that in the second stage of the game implement actions in dominant strategies.

There are 4 possible histories that can prevail at the end of the first-stage monitoring-game. Denoting a particular history with h_k , where $k \in \{1, 2, 3, 4\}$, we formalize these histories as

$$\begin{aligned} h_1 & : (\delta_1, \delta_2) = (m, m), \\ h_2 & : (\delta_1, \delta_2) = (m, n), \\ h_3 & : (\delta_1, \delta_2) = (n, m), \\ h_4 & : (\delta_1, \delta_2) = (n, n). \end{aligned}$$

A contract implements strategies $(\delta_i, e_i^{h_1}, e_i^{h_2}, e_i^{h_3}, e_i^{h_4})_{i=1,2}$ if (i) at any second-stage sub-game that follows history h_k , for $k = 1, 2, 3, 4$, the project choice $e_i^{h_k}$ is borrower i 's dominant strategy, given that he expects borrower $-i$ to undertake the project $e_{-i}^{h_k}$, and (ii) in the first-stage game the strategy about the monitoring decision, δ_i , is borrower i 's dominant strategy, if he expects the borrower $-i$ to choose δ_{-i} .

Specifically, we solve for the optimal group loan contract that implements $(\delta_i, e_i^{h_1}, e_i^{h_2}, e_i^{h_3}, e_i^{h_4})_{i=1,2}$ in dominant strategies. Letting $\pi(h_k)$ denote the induced probability over history h_k , the optimal contract solves

$$\max_{(R_i^{H,H}, R_i^{H,L})} \sum_{k=1}^4 \pi(h_k) \left[p_1(e_1^{h_k}) p_2(e_2^{h_k}) (R_1^{H,H} + R_2^{H,H}) + p_1(e_1^{h_k}) (1 - p_2(e_2^{h_k})) R_1^{H,L} + p_2(e_2^{h_k}) (1 - p_1(e_1^{h_k})) R_2^{H,L} \right] \quad (1a)$$

$$s.t. \quad p_i(e_i^{h_k}) \left[\theta - (p_{-i}(e_{-i}^{h_k}) R_i^{H,H} + (1 - p(e_{-i}^{h_k})) R_i^{H,L}) \right] - \psi^i \cdot \delta_i + e_i^{h_k} \geq 0 \quad (1b)$$

$$e_i^{h_k} = \operatorname{argmax}_{e \in \mathcal{A}_i(h_k)} \left\{ p_i(e) \left[\theta - (p_{-i}(e_{-i}^{h_k}) R_i^{H,H} + (1 - p(e_{-i}^{h_k})) R_i^{H,L}) \right] + e_i \right\} \quad (1c)$$

$$\delta_i = \operatorname{argmax}_{\delta \in \{m, n\}} \left\{ p_i(e_i^{(\delta, \delta_{-i})}) \left[\theta - (p_{-i}(e_{-i}^{(\delta, \delta_{-i})}) R_i^{H,H} + (1 - p(e_{-i}^{(\delta, \delta_{-i})})) R_i^{H,L}) \right] - \psi^i \cdot \delta + e_i^{(\delta, \delta_{-i})} \right\} \quad (1d)$$

In this representation, (1a) is the bank's objective function. The constraint (1b) is borrower i 's participation constraint. Constraints (1c) and (1d) are borrower i 's incentive compatibility constraints, assuming that the contract implements actions in dominant strategies. Constraint (1c) says that, following any history h_k , borrower i takes borrower $-i$'s dominant strategy ($e_{-i}^{h_k}$) as given and optimally chooses his action e from the set of feasible projects available at history h_k , i.e. $\mathcal{A}(h_k)$. Similarly, constraint (1d) is borrower i 's incentive compatibility constraint over monitoring actions, where borrower i takes the dominant strategy of borrower $-i$ as given, δ_{-i} , and plays his best response accordingly, $\delta \in \{m, n\}$, knowing that in the second stage both borrowers will optimally be at the history (δ, δ_{-i}) .

Using the definitions above, we characterize the optimal group lending contract which induces players to coordinate on an equilibrium where borrowers undertake the good project. By construction this is the equilibrium in the economy which maximizes the aggregate welfare, because private projects have negative net present value. Hence, solving for the *good-project-equilibrium* will lead us to obtain the terms of the welfare maximizing group loan contract. Throughout our analysis we assume that in the absence of monitoring, borrowers will be tempted to undertake the high private benefit project - implying without peer monitoring lending would not become socially desirable. Therefore, the optimal contract will be the one, which induces borrowers to monitor each other in the first-stage game and choose the good project in the second-stage game. This means that the bank desires to induce the players coordinate on $(\delta_1, \delta_2) = (m, m)$ in the first stage. In the second stage the socially desirable action is the choice of the good project (0). Formally, the bank prefers the outcome $(e_1, e_2) = (0, 0)$ in the second-stage.

The available actions in the second-stage depend on the prevailing history after the first-stage, since monitoring in the first-stage rules out the high private benefit action from peer's project set. This means conditional on the first-stage outcomes, the strategy space of the second-stage game can include {“the good project”, “the bad project with low private benefit”, and “the bad project with high private benefit”}. For the rest of the analysis, we will call the good project as *action-0*, the bad project with low private benefit as *action-b*, and the bad project with high private benefit as *action-B*.

Our claim is as follows. The least costly way for the bank to ensure that $(\delta_1, \delta_2) = (m, m)$ in the first-stage and $(e_1, e_2) = (0, 0)$ in the second-stage is the unique equilibrium of the dynamic group lending game is as follows: (i) The action- m (monitor) in the first-stage should be a dominant strategy for a particular borrower i and a best response for the borrower j ($\neq i$) given he expects the borrower i to play m ; and, (ii) the action-0 (no private benefit) in the second-stage following the history h_1 should be a dominant strategy for any borrower k and a best response for the borrower l ($\neq k$) given he expects k to

play 0. We will discuss that any deviation from these proposed incentive schemes results in either (a) a no-monitoring equilibrium, or (b) an unstable monitoring equilibrium, or (c) a monitoring equilibrium with inefficiently high transfers from the bank to the borrowers. We will also show that the proposed equilibrium selection is feasible if B is sufficiently large.

We assume that

$$p_1 = p_2,$$

$$\psi_1 = \psi_2,$$

based on which the outcomes at each second-stage sub-game are characterized as follows.

History h_1

As we describe in table 2 below, following the positive monitoring choice of both peers in stage-1, which leads to the history h_1 , the strategy space for the two borrowers contain only two possible actions, $\{0, b\}$, in the second-stage sub-game.

	0	b
0	$p_1(\theta - p_2 R_1^{HH} - (1 - p_2) R_1^{HL}),$ $p_2(\theta - p_1 R_2^{HH} - (1 - p_1) R_2^{LH})$	$p_1(\theta - p_B R_1^{HH} - (1 - p_B) R_1^{HL}),$ $p_B(\theta - p_1 R_2^{HH} - (1 - p_1) R_2^{LH}) + b$
b	$p_B(\theta - p_2 R_1^{HH} - (1 - p_2) R_1^{HL}) + b,$ $p_2(\theta - p_B R_2^{HH} - (1 - p_B) R_2^{LH})$	$p_B(\theta - p_B R_1^{HH} - (1 - p_B) R_1^{HL}) + b,$ $p_B(\theta - p_B R_2^{HH} - (1 - p_B) R_2^{LH}) + b$

Table 2: Second-stage sub-game that follows history h_1

In table 2, we let the row player to represent the borrower 1, and the column player to represent the borrower 2. Accordingly with this choice, the first payoff in each box corresponds to borrower 1, while the second payoff corresponds to borrower 2. As an example, if both borrowers behave diligently and choose the action 0, the payoffs are those in the top-left box, where borrower 1's payoff is $p_1(\theta - p_2 R_1^{HH} - (1 - p_2) R_1^{HL})$, while borrower 2's payoff is $p_2(\theta - p_1 R_2^{HH} - (1 - p_1) R_2^{LH})$.

As we delineated before, at individual payoffs, R_1^{HH} is the repayment of borrower 1 when the projects of both borrowers pay off. R_1^{HL} is the repayment of borrower 1 when his project pays off and borrower 2's doesn't. By limited liability when borrower 1's project does not pay out, no repayment can be enforced from him (since the return from the investment project in the bad state equals to zero). Therefore, we do not specify R_1^{LH} and R_1^{LL} . For borrower 2, similarly R_2^{HH} and R_2^{LH} are respective repayments when both projects pay out and when borrower 2's project pays out borrower 1's doesn't. We allow the possibility of $R_1^{HL} > R_1^{HH}$ as well as $R_2^{LH} > R_2^{HH}$ to capture a joint liability scheme as an outcome of the optimizing contract.

In the second-stage sub-game that follows the history h_1 , $(0, 0)$ is the unique equilibrium if, without loss of generality, (a) for borrower 1 the action 0 (good project) is a dominant strategy and (b) 0 is a best response for borrower 2 given that he expects borrower 1 to play 0. Formally, denoting EU^i as the expected utility from the second-stage sub-game for borrower i , $(0, 0)$ is a unique equilibrium of the sub-game if the following three constraints hold for borrowers 1 and 2:

$$EU^1(0, 0) \geq EU^1(b, 0),$$

$$EU^1(0, b) \geq EU^1(b, b),$$

$$EU^2(0, 0) \geq EU^2(0, b),$$

where in each expectation operator the first argument is borrower 1's action choice and the second argument is borrower's 2 choice of action. These constraints can be expressed as the following:

$$p_1(\theta - p_2 R_1^{HH} - (1 - p_2) R_1^{HL}) \geq p_B(\theta - p_2 R_1^{HH} - (1 - p_2) R_1^{HL}) + b, \quad (2)$$

$$p_1(\theta - p_B R_1^{HH} - (1 - p_B) R_1^{HL}) \geq p_B(\theta - p_B R_1^{HH} - (1 - p_B) R_1^{HL}) + b, \quad (3)$$

$$p_2(\theta - p_1 R_2^{HH} - (1 - p_1) R_2^{LH}) \geq p_B(\theta - p_1 R_2^{HH} - (1 - p_1) R_2^{LH}) + b. \quad (4)$$

Constraints (2) and (3) implement the project-0 a strictly dominant strategy for borrower 1 whereas the constraint 4 is to implement project-0 as a best response for borrower 2 given that he expects the borrower 1 to play 0. The constraint (3) is needed (such that the project-0 becomes a strictly dominant strategy for borrower 1); otherwise, we would end up with multiple equilibria in the sub-game that follows h_1 . Specifically, without $EU^1(0, b) > EU^1(b, b)$, $(0, 0)$ is still a Nash equilibrium in the second-stage game that follows history h_1 ; however, (b, b) would also be a Nash Equilibrium. The multiplicity of equilibria might be undesirable, because low private benefit (b) actions have negative net present value. Therefore, if beliefs regarding coordinating on the bad Nash equilibrium (b, b) are high enough, this might result in with a collapse in lending. Therefore, the action 0 (good project) must be incentivized for at least one of the borrowers as a dominant strategy to rule out the multiplicity.

Also, $(0, 0)$ is still a unique equilibrium if $EU^2(0, 0) > EU^2(b, b)$ holds for borrower 2 in addition to the constraints (2)-(4). We will show below that this constraint holds for borrower 2 as well, implying that the choice of project-0 is a strictly dominating action for him, when we jointly evaluate the equilibrium uniqueness in sub-games that follow histories h_1 and h_2 . Inequalities (2) and (3) together imply

$$\theta - \frac{b}{p_1 - p_B} \geq \max\{p_2 R_1^{HH} + (1 - p_2) R_1^{HL}, p_B R_1^{HH} + (1 - p_B) R_1^{HL}\}. \quad (5)$$

The inequality (4) implies

$$\theta - \frac{b}{p_2 - p_B} \geq p_1 R_2^{HH} + (1 - p_1) R_2^{LH}. \quad (6)$$

We conclude with the following lemma.

Lemma 4.1 *When conditions (5) and (6) are jointly satisfied, $(0, 0)$ is the unique equilibrium of the second-stage game that follows history h_1 .*

History h_2

If borrower 1 monitors whereas borrower 2 doesn't monitor in stage-1, we end up with the history h_2 at the end of the first-stage game. As we describe in table 3 below, in this case the second-stage strategy space for borrower 1 contains all three project opportunities $\{0, b, B\}$ whereas the strategy space for borrower 2 consists of only two projects $\{0, b\}$.

	0	b
0	$p_1(\theta - p_2 R_1^{HH} - (1 - p_2) R_1^{HL}),$ $p_2(\theta - p_1 R_2^{HH} - (1 - p_1) R_2^{LH})$	$p_1(\theta - p_B R_1^{HH} - (1 - p_B) R_1^{HL}),$ $p_B(\theta - p_1 R_2^{HH} - (1 - p_1) R_2^{LH}) + b$
b	$p_B(\theta - p_2 R_1^{HH} - (1 - p_2) R_1^{HL}) + b,$ $p_2(\theta - p_B R_2^{HH} - (1 - p_B) R_2^{LH})$	$p_B(\theta - p_B R_1^{HH} - (1 - p_B) R_1^{HL}) + b,$ $p_B(\theta - p_B R_2^{HH} - (1 - p_B) R_2^{LH}) + b$
B	$p_B(\theta - p_2 R_1^{HH} - (1 - p_2) R_1^{HL}) + B,$ $p_2(\theta - p_B R_2^{HH} - (1 - p_B) R_2^{LH})$	$p_B(\theta - p_B R_1^{HH} - (1 - p_B) R_1^{HL}) + B,$ $p_B(\theta - p_B R_2^{HH} - (1 - p_B) R_2^{LH}) + b$

Table 3: Second-stage sub-game that follows history h_2

In the second-stage sub-game which follows the history h_2 , the bank desires to have $(B, 0)$ as the unique equilibrium of the game, which is true if the project- B is a dominant strategy for borrower 1 and the project-0 is a best response for borrower 2 given he expects the borrower 1 to choose B . The bank incentivizes the action- B for borrower 1 in this sub-game in order to utilize the action B to punish the “no-monitor” behavior of borrower 2 in the first-stage: If borrower 1 chooses B in the second-stage it lowers the likelihood of its own repayment, which under the joint liability scheme will increase the repayment burden on borrower 2 and discipline him to undertake the action to monitor as a best response to borrower 1's monitoring behavior in the first-stage. Formally, the bank desires

$$EU^1(B, 0) \geq EU^1(0, 0),$$

$$EU^1(B, b) \geq EU^1(0, b),$$

$$EU^2(B, 0) \geq EU^2(B, b),$$

which are expressed as the following:

$$p_B(\theta - p_2 R_1^{HH} - (1 - p_2) R_1^{HL}) + B \geq p_1(\theta - p_2 R_1^{HH} - (1 - p_2) R_1^{HL}), \quad (7)$$

$$p_B(\theta - p_B R_1^{HH} - (1 - p_B) R_1^{HL}) + B \geq p_1(\theta - p_B R_1^{HH} - (1 - p_B) R_1^{HL}), \quad (8)$$

$$p_2(\theta - p_B R_2^{HH} - (1 - p_B) R_2^{LH}) \geq p_B(\theta - p_B R_2^{HH} - (1 - p_B) R_2^{LH}) + b. \quad (9)$$

Constraints (7) and (8) implement the project- B as a strictly dominant strategy for borrower 1 and the project-0 as a best response for borrower 2 given he expects the borrower 1 to play B . We would like to highlight that at history h_2 the constraint (8) is needed; otherwise, we would end up with multiple equilibria in the second-stage continuation game following the history h_2 . The undesirability of multiple equilibria in this sub-game can be argued along the lines of our discussions that we presented above at the case of history h_1 .

An immediate question that we need to answer is whether inequalities (2) and (7) can be satisfied at the same time. The answer is yes. The two constraints can be satisfied simultaneously, because $B > b$. Then, the inequalities (7) and (8) can be compactly written as:

$$\theta - \frac{B}{p_1 - p_B} \leq \min\{p_2 R_1^{HH} + (1 - p_2) R_1^{HL}, p_B R_1^{HH} + (1 - p_B) R_1^{HL}\}. \quad (10)$$

The inequality (9) reduces to

$$p_B R_2^{HH} + (1 - p_B) R_2^{LH} \leq \theta - \frac{b}{p_2 - p_B}, \quad (11)$$

and we conclude with the following lemma.

Lemma 4.2 *Inequalities (6) and (11) jointly imply that at the history h_1 playing 0 is also a dominant strategy for the 2nd borrower.*

Therefore, in the sub-game that the bank desires the two borrowers to play in the second-stage, the good project (action 0) is not only a unique Nash equilibrium, but also an equilibrium in dominant strategies.

History h_3

If borrower 1 does not monitor and the borrower 2 monitors in the first-stage game, we end up at history h_3 . As we describe in table 5 below, at history h_3 , the strategy space of the borrower 1 consist of only feasible project options, $\{0, b\}$, whereas the strategy space of the borrower 2 consists of $\{0, b, B\}$.

- Table 5 here -

In the second-stage sub-game that follows history h_3 , similar to history h_2 , the bank would desire to have $(0, B)$ as the unique equilibrium of the second stage sub-game, which is true if the action B is a dominant strategy for borrower 2 and the action 0 is a best response for borrower 1 given he expects the borrower 2 to play B .

Formally, the bank desires that the following conditions to hold for borrowers 1 and 2

$$EU^2(0, B) \geq EU^2(0, 0),$$

$$EU^2(b, B) \geq EU^2(b, 0),$$

$$EU^1(0, B) \geq EU^1(b, B),$$

which can be expressed as the following:

$$p_B(\theta - p_1 R_2^{HH} - (1 - p_1) R_2^{LH}) + B \geq p_2(\theta - p_1 R_2^{HH} - (1 - p_1) R_2^{LH}), \quad (12)$$

$$p_B(\theta - p_B R_2^{HH} - (1 - p_B) R_2^{LH}) + B \geq p_2(\theta - p_B R_2^{HH} - (1 - p_B) R_2^{LH}), \quad (13)$$

$$p_1(\theta - p_B R_1^{HH} - (1 - p_B) R_1^{HL}) \geq p_B(\theta - p_B R_1^{HH} - (1 - p_B) R_1^{HL}) + b. \quad (14)$$

Similar to history h_2 , at history h_3 the constraints (13) and (14) induce the action- B to be a dominant strategy for borrower 2 and the constraint (12) induces the action-0 to be a best response for borrower 1 given that he expects the borrower 2 to play B . We need the constraint (13) in order to rule out multiplicity of equilibria in the second-stage sub-game.

The inequalities (12) and (13) can be compactly written as:

$$\theta - \frac{B}{p_2 - p_B} \leq \min\{p_1 R_2^{HH} + (1 - p_1) R_2^{LH}, p_B R_2^{HH} + (1 - p_B) R_2^{LH}\}. \quad (15)$$

Lemma 4.3 *The inequality (14) will be satisfied as long as the inequality (4) is not violated.*

The lemma 4.3 implies that the implementation of project-0 for a borrower 1 as a strictly dominant strategy at history h_1 also ensures that the project-0 is a best response for the same borrower 1 if the history h_3 would prevail as an outcome of the first-stage game.

History h_4

As we describe in table 6 below, when neither of the players monitor in the first stage game we end up with the history h_4 , where the available actions in the second-stage game include $\{0, b, B\}$ for both borrowers.

At history h_4 , by construction, we assume that both borrowers take the action B , with the following expected utilities:

$$EU^1(B, B) = p_B(\theta - p_B R_1^{HH} - (1 - p_B) R_1^{HL}) + B, \quad (16)$$

$$EU^2(B, B) = p_B(\theta - p_B R_2^{HH} - (1 - p_B) R_2^{LH}) + B. \quad (17)$$

- Table 6 here -

Since the outcome of the sub-game following h_4 is socially undesirable, the bank chooses to implement strategies in the first-stage game to avoid the likelihood of ending up with a history h_4 as an outcome of the first-stage game.

The Supergame

The expected payoffs of the supergame are illustrated in table 4.

The super-game pay-off matrix presents what each continuation sub-game outcome payoffs would be. Specifically, for instance, the payoffs for borrower 1 and borrower 2 when both

	m	n
m	$p_1(\theta - p_2 R_1^{HH} - (1 - p_2) R_1^{HL}),$	$p_B(\theta - p_2 R_1^{HH} - (1 - p_2) R_1^{HL}) + B,$
	$p_2(\theta - p_1 R_2^{HH} - (1 - p_1) R_2^{LH})$	$p_2(\theta - p_B R_2^{HH} - (1 - p_B) R_2^{LH})$
n	$p_1(\theta - p_B R_1^{HH} - (1 - p_B) R_1^{HL}),$	$p_B(\theta - p_B R_1^{HH} - (1 - p_B) R_1^{HL}) + B$
	$p_B(\theta - p_1 R_2^{HH} - (1 - p_1) R_2^{LH}) + B$	$p_B(\theta - p_B R_2^{HH} - (1 - p_B) R_2^{LH}) + B$

Table 4: Supergame

of them monitor each other (m, m) are the outcomes of the sub-game that follows history h_1 as we delineated above.

In the super-game, the bank would like to implement the action to *monitor* as a dominant strategy for one of the borrowers and a best response for the other borrower. Without loss of generality, we pick borrower 1 and implement the monitoring action as a strictly dominant strategy for him, whereas we induce to monitor a best response for the borrower 2 given that he expects the borrower 1 to monitor. Formally, denoting expected super-game payoff of the borrower i with EV^i , we state these conditions as

$$EV^1(m, m) \geq EV^1(n, m),$$

$$EV^1(m, n) \geq EV^1(n, n),$$

$$EV^2(m, m) \geq EV^2(m, n),$$

which can be expressed as the following

$$p_1(\theta - p_2 R_1^{HH} - (1 - p_2) R_1^{HL}) - \psi_1 \geq p_1(\theta - p_B R_1^{HH} - (1 - p_B) R_1^{HL}), \quad (18)$$

$$p_B(\theta - p_2 R_1^{HH} - (1 - p_2) R_1^{HL}) - \psi_1 + B \geq p_B(\theta - p_B R_1^{HH} - (1 - p_B) R_1^{HL}) + B, \quad (19)$$

$$p_2(\theta - p_1 R_2^{HH} - (1 - p_1) R_2^{LH}) - \psi_2 \geq p_2(\theta - p_B R_2^{HH} - (1 - p_B) R_2^{LH}), \quad (20)$$

and can be reduced to:

$$R_1^{HL} - R_1^{HH} \geq \frac{\psi_1}{p_1(p_2 - p_B)}, \quad (21)$$

$$R_1^{HL} - R_1^{HH} \geq \frac{\psi_1}{p_B(p_2 - p_B)}, \quad (22)$$

$$R_2^{LH} - R_2^{HH} \geq \frac{\psi_2}{p_2(p_1 - p_B)}. \quad (23)$$

In the super-game, we need the constraint (19) to hold (such that to monitor is a strictly dominant strategy for the borrower 1) in order to rule out the multiplicity of equilibria in the first-stage monitoring game. Otherwise, in addition to (m, m) the strategies (n, n) also yield another Nash equilibrium, where monitoring doesn't occur. When (n, n) is the outcome of the first-stage game, we end up at history h_4 , which leads to a second-stage sub-game, where the high private benefit bad project (B) is the strictly dominant action for both borrowers. Since action B has a negative net present value; and therefore, undesirable from the perspective of the bank, depending on the belief structure governing the first-stage game, equilibrium multiplicity in the first-stage might imply break down of lending.

Since $p_B < p_2$, it is easy to note that if (22) holds (21) will be satisfied; and, therefore the constraint (21) can be ignored.

Bank's Problem: Now we can state the problem of the bank. The bank implements the unique equilibrium, where borrowers monitor each other in the first-stage game and act diligently in the second-stage and optimizes its profits. Bank's maximization problem is as

follows

$$\max_{R_1^{HH}, R_1^{HL}, R_2^{HH}, R_2^{LH}} p_1[p_2(R_1^{HH} + R_2^{HH}) + (1 - p_2)R_1^{HL}] + (1 - p_1)p_2R_2^{LH} \quad (24)$$

$$s.t. \ R_1^{HL} - R_1^{HH} \geq \frac{\psi_1}{p_B(p_2 - p_B)}, \quad (25)$$

$$R_2^{LH} - R_2^{HH} \geq \frac{\psi_2}{p_2(p_1 - p_B)}, \quad (26)$$

$$\theta - \frac{b}{p_1 - p_B} \geq \max\{p_2R_1^{HH} + (1 - p_2)R_1^{HL}, p_BR_1^{HH} + (1 - p_B)R_1^{HL}\}, \quad (27)$$

$$\theta - \frac{b}{p_2 - p_B} \geq \max\{p_1R_2^{HH} + (1 - p_1)R_2^{LH}, p_BR_2^{HH} + (1 - p_B)R_2^{LH}\}, \quad (28)$$

$$\theta - \frac{B}{p_1 - p_B} \leq \min\{p_2R_1^{HH} + (1 - p_2)R_1^{HL}, p_BR_1^{HH} + (1 - p_B)R_1^{HL}\}, \quad (29)$$

$$\theta - \frac{B}{p_2 - p_B} \leq \min\{p_1R_2^{HH} + (1 - p_1)R_2^{LH}, p_BR_2^{HH} + (1 - p_B)R_2^{LH}\}, \quad (30)$$

together with non-negativity of the set $\{R_1^{HH}, R_1^{HL}, R_2^{HH}, R_2^{LH}\}$ and limited liability of the borrowers such that the elements of $\{R_1^{HH}, R_1^{HL}, R_2^{HH}, R_2^{LH}\}$ do not exceed θ . First, we note that constraints (29) and (30) are satisfied for B large enough. Therefore, we ignore these two constraints for the moment. From (25) and (26) we can observe the joint liability property of the optimal group lending contract, which we formally state in the following proposition.

Proposition 4.4 $R_1^{HL} > R_1^{HH}$ and $R_2^{LH} > R_2^{HH}$.

Using the joint liability property at (27) and (28) shows that

$$[p_2R_1^{HH} + (1 - p_2)R_1^{HL}] - [p_BR_1^{HH} + (1 - p_B)R_1^{HL}] = (p_2 - p_B)(R_1^{HH} - R_1^{HL}) < 0, \quad (31)$$

$$[p_1R_2^{HH} + (1 - p_1)R_2^{LH}] - [p_BR_2^{HH} + (1 - p_B)R_2^{LH}] = (p_2 - p_B)(R_2^{HH} - R_2^{LH}) < 0, \quad (32)$$

which reduces constraints (27) and (28) to:

$$\theta - \frac{b}{p_1 - p_B} \geq p_BR_1^{HH} + (1 - p_B)R_1^{HL}, \quad (33)$$

$$\theta - \frac{b}{p_2 - p_B} \geq p_BR_2^{HH} + (1 - p_B)R_2^{LH}. \quad (34)$$

Therefore, we are left with 4 inequalities and 4 unknowns. R_1^{HH} enters constraints (25) and (33) with the same sign. Therefore, given R_1^{HL} the bank will desire to raise R_1^{HH} such that constraints (25) and (33) will both be binding. The same property is true for (26) and (34). Then, solving (25) and (26) with equality yields:

$$R_1^{HH} = R_1^{HL} - \frac{\psi_1}{p_B(p_2 - p_B)},$$

$$R_2^{HH} = R_2^{LH} - \frac{\psi_2}{p_2(p_1 - p_B)}.$$

Plugging these in - binding - (33) and (34) provides:

$$R_1^{HL} = \theta - \frac{b}{p_1 - p_B} + \frac{p_B \psi_1}{p_B(p_2 - p_B)}, \quad (35)$$

$$R_2^{LH} = \theta - \frac{b}{p_2 - p_B} + \frac{p_B \psi_2}{p_2(p_1 - p_B)}. \quad (36)$$

Solving for R_1^{HH} and R_2^{HH} provides the repayments for borrowers 1 and 2 when both projects have the high return realization:

$$R_1^{HH} = \theta - \frac{b}{p_1 - p_B} - \frac{\psi_1}{p_2 - p_B} \left(\frac{1 - p_B}{p_B} \right), \quad (37)$$

$$R_2^{HH} = \theta - \frac{b}{p_2 - p_B} - \frac{\psi_2}{p_1 - p_B} \left(\frac{1 - p_B}{p_2} \right). \quad (38)$$

Comparing (35) against (36) and (37) against (38) provides the following result.

Proposition 4.5 $R_1^{HH} < R_2^{HH} < R_2^{LH} < R_1^{HL}$ even if $p_1 = p_2 \equiv p$ and $\psi_1 = \psi_2$.

Proposition 4.4 indicates a heterogeneity in optimal repayment rates. This heterogeneity implies the presence of a “monitoring incentivized” borrower within a homogeneous group, who overpays in bad states and gets compensated in good states. Specifically, borrower 1 takes the burden - and hence the penalty - of the joint liability by paying significantly more in bad states and taking care of his peer, which disciplines him and induces a strictly dominating monitoring action in the first-stage game. Borrower 1 gets his reward in high states by underpaying relative to borrower 2.

Now, let us define

$$p_1 = p_2 \equiv p,$$

$$\psi_1 = \psi_2 \equiv \psi.$$

The expected utility of borrowers 1 and 2 and the bank are expressed as the following:

$$\begin{aligned} EV_1(m, m) &= p \left\{ \theta - p \left[\theta - \frac{b}{p - p_B} - \frac{\psi}{p - p_B} \left(\frac{1 - p_B}{p_B} \right) \right] - (1 - p) \left[\theta - \frac{b}{p - p_B} + \frac{\psi}{p - p_B} \right] \right\}, \\ &= \frac{p}{p - p_B} \left[b + \psi \left(\frac{p}{p_B} - 1 \right) \right], \end{aligned} \quad (39)$$

$$\begin{aligned} EV_2(m, m) &= p \left\{ \theta - p \left[\theta - \frac{b}{p - p_B} - \frac{\psi}{p - p_B} \left(\frac{1 - p_B}{p} \right) \right] - (1 - p) \left[\theta - \frac{b}{p - p_B} + \frac{p_B}{p} \frac{\psi}{p - p_B} \right] \right\}, \\ &= \frac{p}{p - p_B} \left[b + \frac{p_B}{p} \psi \left(\frac{p}{p_B} - 1 \right) \right]. \end{aligned} \quad (40)$$

$$EV_{bank} = \left\{ p\theta - 1 - \frac{p}{p - p_B} \left[b + \psi \left(\frac{p}{p_B} - 1 \right) \right] \right\} + \left\{ p\theta - 1 - \frac{p}{p - p_B} \left[b + \frac{p_B}{p} \psi \left(\frac{p}{p_B} - 1 \right) \right] \right\}. \quad (41)$$

We finalize our theoretical discussion with the following result.

Proposition 4.6 $EV_1(m, m) > EV_2(m, m)$.

Evaluating propositions 4.4 and 4.5 together shows that the optimal group loan contract implies that borrower 1 experiences a more volatile consumption profile compared to borrower 2; however, the overall expected consumption of borrower 1 is greater than borrower 2's expected consumption. This result is quite crucial, because it points out the desirability of a “group leader”, who is willing to accept consumption volatility in return for an expected consumption premium. We delineate our discussions concerning group leaders and heterogeneity in repayment terms below in section 5.

We would like to highlight that our results hold as long as $\psi < b$; otherwise, the repayment in the low-state of the other induces a transfer from the borrower to the bank, which implies the violation of the limited liability constraint as we discussed before.

5 Discussion

What drives the optimality of heterogeneous repayment rates in the group lending framework that we analyze? The technical answer is the presence of the strong constraint (19) that should hold for borrower 1, which reduces to

$$R_1^{HL} - R_1^{HH} \geq \frac{\psi_1}{p_B(p_2 - p_B)},$$

and the lack of analog constraint for borrower 2.

Above we explained that we need this constraint in order to rule out an undesirable multiple equilibria situation in the first-stage game. The intuition is straightforward, a “no-monitoring” equilibrium in the first-stage game leads to socially inefficient high private benefit actions in sub-sequent second-stage games. The next question that we need to address is why the bank would not impose the analog of constraint (19) for borrower 2? The answer is that, because imposing this additional constraint would set the repayments of two borrowers equal such that $R_1^{HH} = R_2^{HH} \equiv R^H$ and $R_1^{HL} = R_2^{LH} \equiv R^L$ with:

$$R^H = \theta - \frac{b}{p - p_B} - \frac{\psi}{p - p_B} \left(\frac{1 - p_B}{p_B} \right), \quad (42)$$

$$R^L = \theta - \frac{b}{p - p_B} + \frac{p_B \psi}{p_B(p - p_B)}. \quad (43)$$

Comparing (42) and (43) against the repayment rates we obtained in the previous section - (35) through (38) - shows that when monitoring is a strictly dominant strategy for both borrowers, the expected aggregate repayment that bank would obtain from the group is lower compared to the case where monitoring is strictly dominant for only one player. The intuition is that incentivizing monitoring increases rents that need to be redistributed to borrowers resulting from the monitoring action.

Repayment heterogeneity and in particular assigning a borrower to take care the burden of the joint-liability in bad states and rewarding him in good states suggests that a “leader” among a group of homogeneous borrowers is an outcome of the optimal group lending

contract. Group leaders are commonly practiced by microfinance institutions as part of joint-liability agreements. For instance, Gramin Vikash Bank, a leading microfinance institution in India, states on its web-site the following: “The (group) leader fosters a sense of unity, oversees and maintains discipline, shares information and facilitates repayments. For the bank, he is the focal point for group activities.”¹ In other words, the group leader is the intermediary between the group of borrowers and the bank. As discussed by van Eijkel et al. (2009), depending on the structure of the loan contract, group leaders may be paid for their intermediation services. Microfinance institutions all around the world apply similar “group leadership” agreements at joint-liability lending contracts. To this end, some other leading microfinance institutions, which require group leadership at joint-liability lending contracts Grameen Bank in Bangladesh, Banco Sol in Bolivia and Bank Rakyat in Indonesia.

There is a number of empirical studies, highlighting the role of group leaders in enhancing the performance of joint liability contracts. Paxton et al. (2000) use data of 140 group borrowers from a micro lending institution in Burkina Faso and find that the quality of the group leader in running the group transactions is positively related to the repayment performance, which may be seen as evidence for the importance of the group leader at joint-liability schemes. Hermes et al. (2005) investigate the role of the group leader in reducing moral hazard. The authors use dataset of 102 groups from Eritrean group lending institutions. They find evidence that monitoring of the group leader reduce moral hazard behaviour of group members. In a related paper the same authors show that the role of the group leader is highly relevant for improving the repayment performance of the group (Hermes et al., 2006).

Existing theoretical literature on joint liability lending contracts hardly dealt with the specific role of the group leader in fostering the performance of group lending mechanisms. However, the institutional lending practices mentioned above as well as the empirical evidence suggest a vital role for the leader in the functioning of the group. To the best

¹<http://www.bgvb.co.in/JointLiabilityGroup.aspx>

of our knowledge, the two exceptions in the literature are van Eijkel et al. (2009) and Katzur and Lensink (2010). Van Eijkel et al. (2009) show that in a group lending contract the entrepreneur with the highest future profits is motivated to put the highest effort to peer monitor and would desire to become the group leader. Similarly, Katzur and Lensink (2010) find that a relatively risky borrower would choose to act as a group leader and take responsibility for his peers' repayment, in return for a discount on his own loan repayment.

The key difference between our model and the above mentioned two studies is that we do not assume an ex-ante heterogeneity among the group of borrowers, such as heterogeneity in risk attitudes and profitability. Therefore, our paper makes several key contributions to the theoretical literature on joint-liability lending contracts with endogenous group leadership. First, we characterize the properties of an optimal group lending contract using a fairly standard moral hazard framework. Second, we endogenously derive the key characteristics of a group leader that are comparable to the group leader features observed in practice. Third, we show that optimal contracts imply the desirability of a group leader even within a group of borrowers with homogeneous characteristics. And fourth, our characterization addresses the question of why someone would be willing to become a group leader and undertake a socially desirable but individually costly action by showing that the group leader who takes care of the burden of joint-liability gets compensated in expected terms as an outcome of the optimal joint liability contract.

6 Conclusion

We developed a group lending framework where peer monitoring determines the benefits from private benefit actions of borrowers. In our framework, a borrower chooses to monitor his peer only if this is in his best interest. Therefore, the bank has to consider borrowers' incentives at making them jointly liable for each other's behavior. Under this framework, we characterized the optimal group lending contract. We showed that the optimal group contract exhibits a joint liability scheme. Furthermore, we also showed that the optimality requires a group leader, who overpays in bad states and gets compensated in good

states. Our work rationalizes the widely applied *group-leadership* concept of microfinance programmes as an outcome of an optimal lending contract.

Our conclusions make important contributions to the theoretical literature on joint-liability lending. We characterized the properties of an optimal group lending contract using a fairly standard moral hazard framework. Second, we derived the key characteristics of a group leader that are comparable to the group leader features observed in practice. Third, we showed that optimal contracts imply the desirability of a group leader even within a group of borrowers with homogeneous characteristics. And fourth, using our characterization we addressed the question of why someone would be willing to become a group leader and undertake a socially desirable but individually costly action.

The introduction of a group-leader is an efficient endogenous mechanism that rules out the possibility of coordination failures in the implementation of the efficient contract. We obtained this result within the most simple setup that we could consider: we assumed that the bank implements actions in dominant strategies. To this end, it would be interesting to generalize the coordination game. A possibility would be to model a global game environment, where borrowers receive noisy signals on the enforcement choice other borrowers. We conjecture that the noise structure will select the equilibrium of play, and the role of a group leader will depend on how noisy the signal is.

It would be also interesting to generalize our model to the case of an arbitrary N -number of borrowers: With such specification, would there be just one group-leader? And how would the optimal incentive structure look like? Would there be hierarchy among the borrowers? These are all interesting extensions that go beyond the purpose of the paper, and we leave them to future research.

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	0	b	B
0	$p_1(\theta - p_2 R_1^{HH} - (1 - p_2) R_1^{HL}),$	$p_1(\theta - p_B R_1^{HH} - (1 - p_B) R_1^{HL}),$	$p_1(\theta - p_B R_1^{HH} - (1 - p_B) R_1^{HL}),$
	$p_2(\theta - p_1 R_2^{HH} - (1 - p_1) R_2^{LH})$	$p_B(\theta - p_1 R_2^{HH} - (1 - p_1) R_2^{LH}) + b$	$p_B(\theta - p_1 R_2^{HH} - (1 - p_1) R_2^{LH}) + B$
b	$p_B(\theta - p_2 R_1^{HH} - (1 - p_2) R_1^{HL}) + b,$	$p_B(\theta - p_B R_1^{HH} - (1 - p_B) R_1^{HL}) + b,$	$p_B(\theta - p_B R_1^{HH} - (1 - p_B) R_1^{HL}) + b$
	$p_2(\theta - p_B R_2^{HH} - (1 - p_B) R_2^{LH})$	$p_B(\theta - p_B R_2^{HH} - (1 - p_B) R_2^{LH}) + b$	$p_B(\theta - p_B R_2^{HH} - (1 - p_B) R_2^{LH}) + B$

Table 5: Second-stage sub-game that follows history h_3

	0	b	B
0	$p_1(\theta - p_2 R_1^{HH} - (1 - p_2) R_1^{HL}),$	$p_1(\theta - p_B R_1^{HH} - (1 - p_B) R_1^{HL}),$	$p_1(\theta - p_B R_1^{HH} - (1 - p_B) R_1^{HL}),$
	$p_2(\theta - p_1 R_2^{HH} - (1 - p_1) R_2^{LH})$	$p_B(\theta - p_1 R_2^{HH} - (1 - p_1) R_2^{LH}) + b$	$p_B(\theta - p_1 R_2^{HH} - (1 - p_1) R_2^{LH}) + B$
b	$p_B(\theta - p_2 R_1^{HH} - (1 - p_2) R_1^{HL}) + b,$	$p_B(\theta - p_B R_1^{HH} - (1 - p_B) R_1^{HL}) + b,$	$p_B(\theta - p_B R_1^{HH} - (1 - p_B) R_1^{HL}) + b$
	$p_2(\theta - p_B R_2^{HH} - (1 - p_B) R_2^{LH})$	$p_B(\theta - p_B R_2^{HH} - (1 - p_B) R_2^{LH}) + b$	$p_B(\theta - p_B R_2^{HH} - (1 - p_B) R_2^{LH}) + B$
B	$p_B(\theta - p_2 R_1^{HH} - (1 - p_2) R_1^{HL}) + B,$	$p_B(\theta - p_B R_1^{HH} - (1 - p_B) R_1^{HL}) + B,$	$p_B(\theta - p_B R_1^{HH} - (1 - p_B) R_1^{HL}) + B$
	$p_2(\theta - p_B R_2^{HH} - (1 - p_B) R_2^{LH})$	$p_B(\theta - p_B R_2^{HH} - (1 - p_B) R_2^{LH}) + b$	$p_B(\theta - p_B R_2^{HH} - (1 - p_B) R_2^{LH}) + B$

Table 6: Second-stage sub-game that follows history h_4